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## Paper Session I-A - Advanced Solid Rocket Motor (ASRM)

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## ADVANCED SOLID ROCKET MOTOR (ASRM)

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### ABSTRACT

The Advanced Solid Rocket Motor (ASRM) is a 150-in. diameter segmented motor design that incorporates substantive design changes to improve the reliability and design safety margins of the space shuttle system. The new motor thrust characteristics are tailored to preclude the necessity for throttling the Space Shuttle Main Engines (SSME) during the period of maximum dynamic pressure. This reduces or eliminates about 175 criticality 1/1R failure modes for the shuttle system. Furthermore, the ASRM is designed to provide a 12,000 lb payload improvement which will support space station development and other critical NASA missions.

To achieve the level of process control and automation needed for high quality, reproducibility, and improved reliability, NASA concluded that a substantially new modern, fully-automated facility is required. Sites selected to produce and test the ASRM are the TVA Yellow Creek Mississippi site and the Stennis Space Center site, respectively.

The ASRM design/program evolved from Phase A studies conducted in late 1986 and Phase B studies conducted from mid-1987 to April 1988. All major solid propulsion contractors participated in these studies. The study results culminated in the release of an ASRM Request for Proposals (phase C/D) October 31, 1988. Authority to proceed (ATP) with the Development and Verification Program is currently planned for April 1, 1989, with the first ASRM Shuttle development flight tentatively scheduled for late 1994.

### BACKGROUND

ASRM Phase A (also called block II) studies were conducted by NASA in late 1986, with the participation of all the major Solid Rocket Propulsion contractors. The design studies, with emphasis on SRM joint designs, were structured to be responsive to the MSFC Redesign Team's critique of the current motor design. Following the Phase A study effort and based, in part, on results of these studies, NASA presented to Congress a "Space Shuttle Solid Rocket Motor Proposed Acquisition Strategy and Plan," dated March 1987. This plan analyzed three options to develop procurement strategy and planning for the future Solid Rocket Motor (SRM) Program. These options were as follows:

1. Recompensation of the Redesign SRM (RSRM)
2. Continued Single Source Procurement of the Redesign SRM
3. Competition of an Advanced (Upgraded) SRM

Option 3, the recommended and accepted option, responded to the need for competition, higher SRM reliability and flight safety, and the need for more booster performance through design changes. Additional improvement in SRM reliability would be achievable by adoption of modern automated manufacturing plant operations to reduce the potential for human error. The process control and automation would also reduce the unit production cost.

Predicated on the acceptance of the recommendations contained in the "Acquisition Plan," NASA issued (August 1987) five parallel Phase B contracts, directed toward ASRM reliability and

performance improvements for both segmented (like the current motor) and monolithic (single cast grain structure) design concepts. Also included was the requirement to perform a detailed producibility analysis and design study for a modern, automated ASRM facility to maximize quality control and reliability.

In October 1987, the "NASA Authorization Act" recognized the need for an ASRM which would enhance the margin of safety, reliability, and performance of the Space Shuttle. The Act also recognized that the solid rocket motor project would benefit from competition and, therefore, directed the issuance of a Request for Proposals for the advanced solid rocket motor by the time the FY 1990 budget was submitted to Congress.

Figure 1 summarizes the ASRM acquisition schedule set forth by the Authorization Act of 1988.

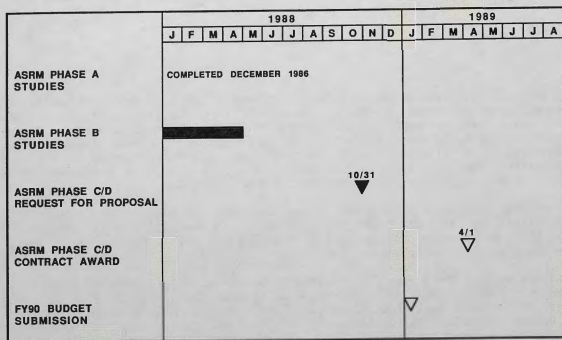


Figure 1. ASRM Acquisition Schedule

#### Phase A ASRM Study Summary

Five Phase A study contracts were issued to define alternate designs and planning to support Space Shuttle requirements. The studies were conducted by Aerojet Solid Propulsion Company; Atlantic Research Corporation; Hercules, Incorporated; Morton Thiokol, Incorporated; and United Technologies Corporation, Chemical Systems Division. There were no technical constraints other than the Space Shuttle Solid Rocket Motor envelope, performance, and materials criteria. Products of these studies included design concepts with supporting analyses, a recommended development plan, an end item specification, an assessment of corporate capabilities, and program cost estimates.

The Phase A study recommendations were evaluated by separate NASA Technical and Resource Teams to determine the technical merit and the programmatic requirements.

The Teams consisted of MSFC, KSC, JPL, and JSC personnel who assessed the specific design concepts and cost offered by the five contractors. The Team's Phase A study conclusions are summarized as follows:

- o The segmented and monolithic design concepts could reduce the SRM failure modes and, hence, improve reliability and flight safety margins. However, the technology necessary for large monolithic SRMs has not been adequately demonstrated.
- o The performance improvement could increase payload capabilities by up to 7,200 lbs. Additional payload capability could be achieved with a more energetic propellant system to provide a total increase of approximately 10,000 lbs.

- o The cost projections were reasonable and consistent with the existing SRM project cost data base.

#### Phase B ASRM Studies

The five participants in the Phase A studies were selected through a follow-on open competition, and were awarded contracts in August 1987 to further define the ASRM concepts and attendant facilities. Each contract period of performance was 9 months. The contracts resulted in the following information/data:

- a. ASRM Design - Trade studies and comparative analyses of case, nozzle, propellant, liner/insulation, and ignition subassemblies for segmented and monolithic designs that maximized flight safety and reliability and met requirements of the Design and Performance Requirements Document. Design selections/recommendations based on flight safety and reliability, producibility and quality control, performance, and cost. A 12,000 lb Shuttle payload gain resulted in a case diameter increase of approximately 4 in.
- b. Advanced SRM Production and Testing Facility Design - Preliminary engineering data for an ASRM production and test facility that maximized ASRM producibility and quality as a means of providing optimum reliability. Definition of automated processes and controls to minimize process error and maximize process repeatability. Facility design studies accommodating either monolithic or segmented ASRMs.
- c. Programmatic Data - Preliminary master schedules, time phased cost estimates, major tests and verification plans, and identification of major technical or programmatic risks.
- d. Additional Performance Capability - Identification of concepts and modifications to the basic designs to achieve additional payload capabilities of up to 20,000 lbs relative to the ASRM.

Predicated on Phase B study products, NASA baselined programmatic decisions that were fundamental to the definition of the ASRM procurement.

- a. Design Concept - Preliminary design studies and recommendations were provided by the ASRM Phase B contractors for both monolithic and segmented motor designs. NASA elected to proceed with a segmented motor for the ASRM development. The decision was predicated upon substantive improvements in flight safety, reliability, and performance (relative to the Redesigned SRM) while minimizing the development risk through the applicability of existing experience, data bases, and launch support facilities. The design concepts for the segmented motors enhance the flight safety margins and producibility (and, hence, quality and reliability) of the ASRM through welded factory joints, field joints that close upon motor pressurization, and elimination of asbestos bearing materials, redesign and simplification of the nozzle, and the use of mechanization and automation in place of labor intensive operations.

The intuitive attractiveness of the monolithic motor is the potential for additional flight safety margins due to elimination of most field joints, the elimination of joint manufacturing operations, and the reduction of stacking operations at the launch site. A prerequisite to the attainment of these apparent benefits for the monolithic motor is an extensive developmental effort, with associated programmatic risk, to establish the procedures for and consistency of casting and curing one million pound quantities of propellant, to develop the tooling and methodology for positioning and safe extraction of casting mandrels, to validate the ballistic reproducibility of the motors, and to develop transportation and handling procedures and facilities to accommodate the monolithic motor (Figure 2).

- b. Facilitation - The selection of the ASRM facilitization approach was accomplished by an Intercenter Facility Steering Group that analyzed Phase B contractor data and the results of NASA studies, analyses, and considerations. Contractor data indicate that a new facility is required to achieve the level of process control and automation needed to materially enhance the quality and reproducibility of Shuttle scale solid rocket motors. The Phase B contractor data generally favored a new Government Owned Contractor Operated (GOCO) facility to be designed, constructed, and operated by a contractor on Government property. The findings were based on an apparent lower total Government cost,

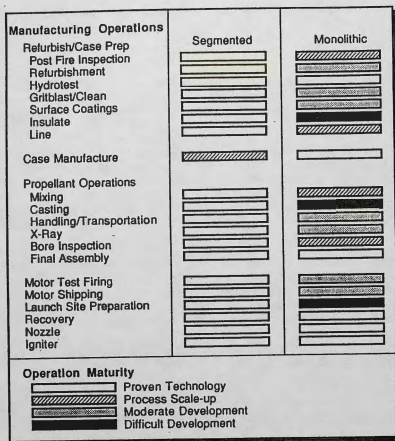


Figure 2. Segmented Versus Monolithic Development Risk

reduced termination liability, acquisition of permits, equalization of competition, and flexibility for NASA in terms of utilization, modernization, growth, and recompetition of contract effort

A modern, optimized processing facility for ASRM will entail the introduction of stringent process controls and automation features into nearly every operation in the production of the motor. The current motor production entails labor intensive operations that lead to variations between motors and increase exposure to hazards. To achieve the intended level of quality and reliability, the process flow and the resultant facility must be optimized so that operations progress in an orderly manner, cleanliness and environmental controls are provided for critical processes, processes can be fully automated where beneficial, in-line inspection and evaluation are provided to insure integrity from step to step, and industrial safety and environmental protection measures are fully integrated into the production. Solid motor processing facilities are unique and are configured by the safety, environmental, and process automation and control requirements. Although modification of facilities would seem to offer a lower investment, the magnitude of changes contemplated would necessitate extensive renovation of existing facilities and complete disruption of any on-going activities. The resultant plant must also be adaptable for change and growth in terms of motor size and quantities.

These considerations lead to the conclusion that a new, optimized production plant, with access to both rail and water transportation, is required.

The key factors of the Phase B studies and NASA data that were analyzed in establishing the recommendation for a new facility included the following:

- o Producibility and Process Optimization
- o Cost of Operation
- o Growth Potential
- o Facility Investment Cost/Risk
- o Environmental Factors
- o Industrial and Public Safety

Based on these factors, NASA selected the TVA Yellow Creek site in Mississippi for the manufacture and production facility and the Stennis Space Center for testing of the ASRM's.

## ASRM DESIGN

### Goals and Objectives

The ASRM program goals are to enhance shuttle system safety and performance. The specific objectives are to: improve flight safety design margins, improve system reliability through enhanced quality and reproducibility, achieve full shuttle payload capability, optimize program cost, encourage commercial initiatives, and promote a competitive solid rocket motor industry.

### Design Features

The improved flight safety design margins and reliability are achieved by mechanical and ballistic redesigns and by quality and reproducibility enhancements through producibility changes:

- o Field joints are designed to close rather than open when the motor is pressurized, eliminating the most likely cause of joint leakage.
- o The number of factory joints is reduced through use of weldable case materials, eliminating four Criticality 1 failure modes.
- o The insulation closeout design restricts hot gas leakage to the mechanical joints.
- o The thrust time characteristics (Figure 3) are tailored to preclude the necessity to throttle the SSME during the region of maximum dynamic pressure; thus, eliminating or reducing approximately 175 Criticality 1 and 1R failure modes for the SSME and the Auxiliary Power Units.

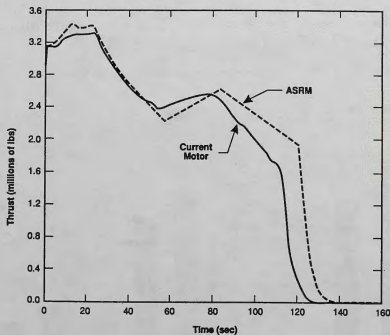


Figure 3. Thrust Profile

- o The nozzle redesign reduces the number of parts and the number of joints, eliminating about 16 Criticality 1 and 1R failure modes.
- o The asbestos-bearing materials are to be replaced.
- o Incorporation of process controls and automation eliminate labor intensive operations, and will improve motor quality, motor-to-motor reproducibility, and industrial safety. Figure 4 depicts typical sources of current Motor Design Defects.



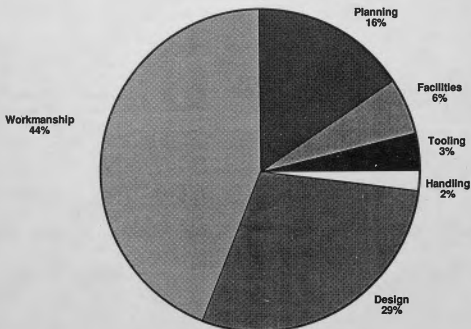


Figure 4. Sources of Motor Defects

#### Safety Enhancement

Figure 5 illustrates the projected improvement in Criticality 1 and 1R failure modes for the ASRM. Improvements in motor quality and flight reliability are the predominate factors in reducing overall program operational cost.

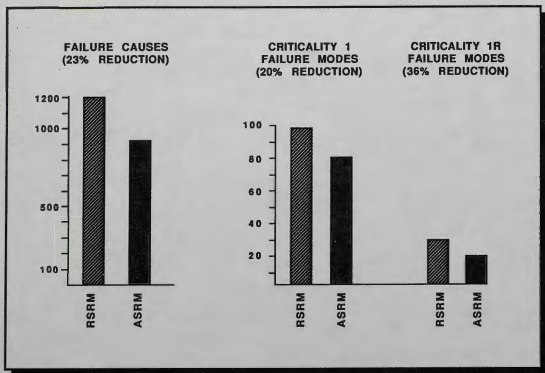


Figure 5. ASRM Safety Enhancement

## Performance Improvement

The enhancement of payload performance is also a significant factor in program cost reduction. The projected 12,000 lb payload capability improvement of the ASRM, as shown in Figure 6, is equivalent to a 17% increase in Shuttle utilization or an additional 2.4 equivalent Shuttle missions per year (for a mission model of 14 flights per year), based upon historical and forecast payload loading factors. The added payload performance will produce an early economic return on Government investment.

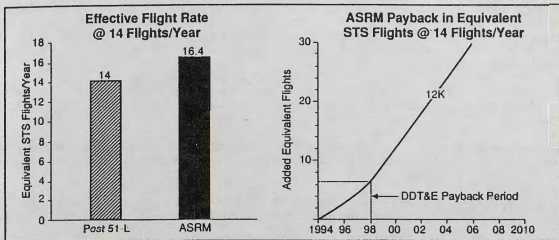


Figure 6. ASRM - Payback Begins with First Flight

The increased payload performance is achieved by use of a higher performance propellant (HTPB), increased quantity of propellant (larger diameter, 150 in.), reduced inert weight of the motor, and thrust profile optimization. The projected STS payload capability is shown in Figure 7 for the ASRM relative to the Redesign Solid Rocket Motor at the normal SSME power level of 104%. The original Shuttle performance goal was 65,000 lbs to 150 n.mi. (28.5°).

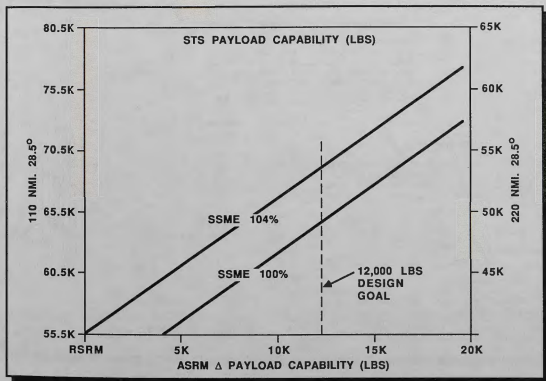


Figure 7. STS Payload Enhancements



For the long term, the ASRM will support the deployment of the Space Station and other critical payloads, retain a competitive solid motor industrial base, and provide a building block for future national space booster requirements.

### ASRM PROGRAM PLAN

The authority to proceed with the design, development, test, and evaluation effort (DDT&E) for ASRM is tentatively scheduled for April 1, 1989. The selected contractor will be totally responsible for the product, and will provide all development hardware, facilities, equipment, tooling, and spares to accomplish the design and development, and will conduct a comprehensive verification program. The verification program will provide the necessary data for evaluation of the final design and manufacturing process, and will provide traceability of all requirements to their verification. The test program will begin with material and component testing, subscale motor firings, and conclude with full-scale flight configuration motor firings embracing the added verification discipline of the RSRM program. Included with DDT&E effort is six Development Flights prior to operational status.

The selected contractor will also provide a very comprehensive aerospace system engineering and integration effort to define requirements and insure compliance of every aspect of the ASRM with those requirements, and to provide in-depth engineering for every required discipline.

Concurrent with the DDT&E contract, the design and construction of a modern, automated production and test facility capable of producing at least 16 flight sets of ASRM hardware per year will be initiated.

At the appropriate time in the DDT&E contract, a Production and Operation follow-on contract will be solicited to accomplish the transition from the RSRM to the ASRM in the Shuttle Program.

Figure 8 represents the schedule for the ASRM DDT&E Project. With the emphasis on the Systems Engineering and Integration as well as the Verification Program, very specific schedules will be developed for the DDT&E project.

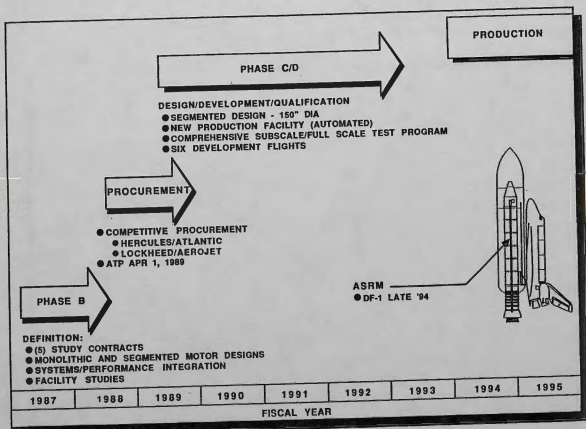


Figure 8. ASRM Program Schedule